Software Stacks for Mixed-critical Applications: Consolidating IEEE 802.1 AVB and Time-triggered Ethernet in Next-generation Automotive Electronics

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Agenda

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Definition

A Mixed-Critical Application joins traffic flows and tasks of **different classes** of **real-time** requirements

Typical Characteristics

- Traffic flows with diverging timing requirements
- Different communication patterns
  - Synchronous (time-triggered)
  - Asynchronous (event-triggered)

Advanced Driver Assistance Systems, e.g. Active Body Control (ABC)-System

- Synchronization of (Stereo) Cameras
  - Transmission with medium precision and latency requirements.
  - Calculation of timestamps requires highest precision
- Transfer Raw Images
  - Transfer images with low latency.
  - Jitter is allowed up to 10% of image cycle (order of milliseconds)
- Control actuators (e.g. active suspension)
  - Physical control loop
  - Least latency required for best control results
  - Least jitter required to guarantee stable system

Problem
Challenges for Automotive Mixed-critical Application

- Challenging timing
  - Latency below 250 µs
  - Jitter below 10 µs
- High bandwidth
  - For cameras, laser, radar up to 100 Mbps (soon more)
- Limited hardware resources
  - Weak processors
  - Low memory
  - Low energy consumption

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Contribution

Software-Stack Architecture

- For automotive Embedded Systems
- Providing **parallel** support for
  - Time-triggered real-time communication
  - Ethernet AVB streams
- Prototype implementation for upcoming IEEE 802.1Qbv

Background
Audio/Video Bridging (IEEE 802.1BA[1])

Basic parts:

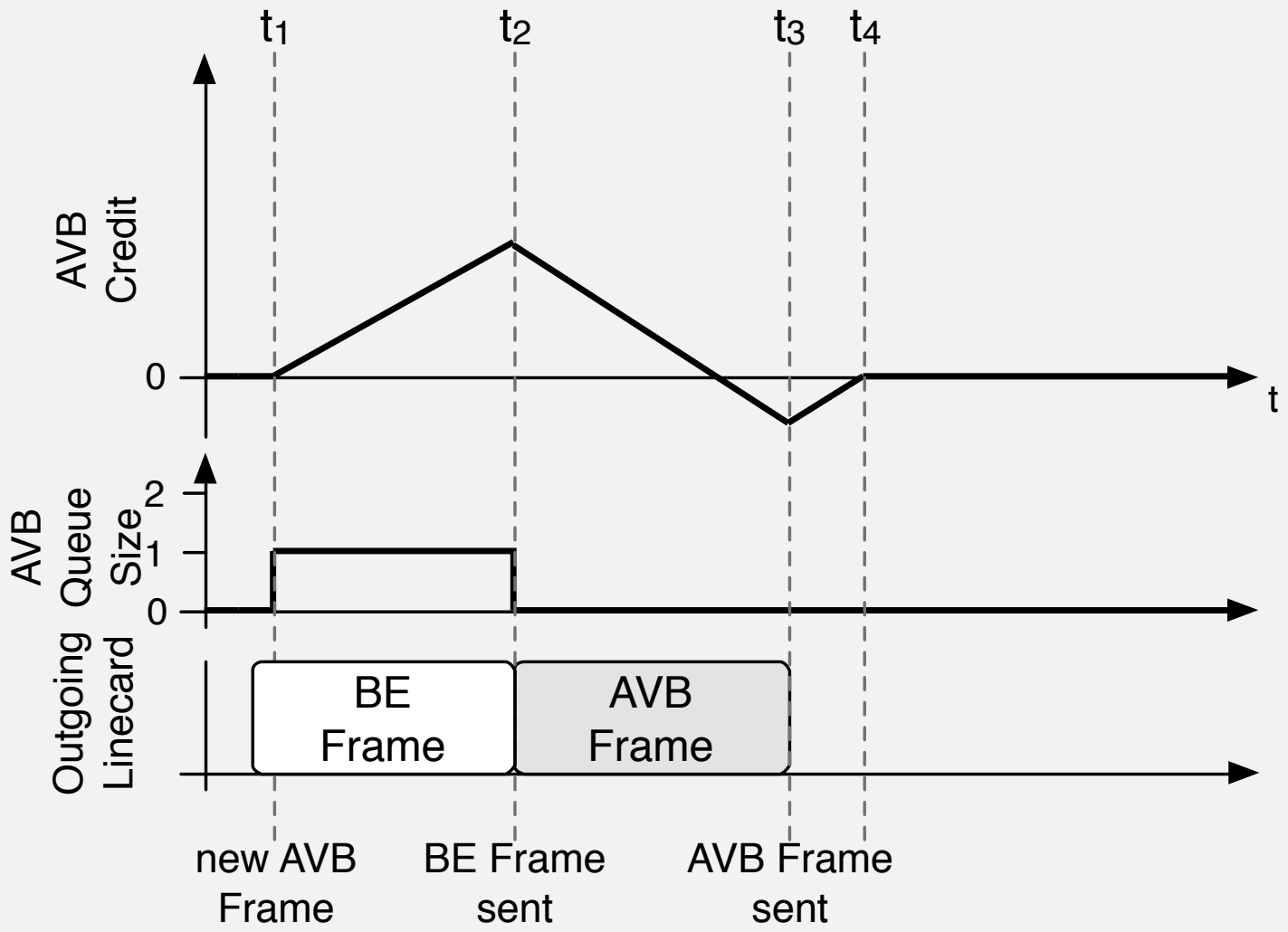
- Credit Based Shaper (IEEE 802.1Qav)
- Stream Reservation Protocol (IEEE 802.1Qat)
- Link Layer Discovery Protocol (IEEE 802.1AB)
- Subset of PTP (IEEE 802.1AS)

Traffic classes:

- Class A (max. latency 2 ms within 7 hops)
- Class B (max. latency 50 ms within 7 hops)
- Best-Effort (BE)

[1] Institute of Electrical and Electronics Engineers: *IEEE 802.1BA - IEEE Standard for Local and metropolitan area networks - Audio Video Bridging (AVB) Systems*. Sept. 2011.

- Key part for extending AVB with additional traffic
- Separate credit per SR Class
- Credit value changes with two gradients:
  - Sendslope, represents: reserved bandwidth - max. bandwidth
  - Idleslope, represents: reserved bandwidth


t1
t2
t3
t4
AVB Credit
0
t
AVB Queue Size
2
1
0
Outgoing Linecard
BE Frame
AVB Frame
new AVB Frame
BE Frame sent
AVB Frame sent

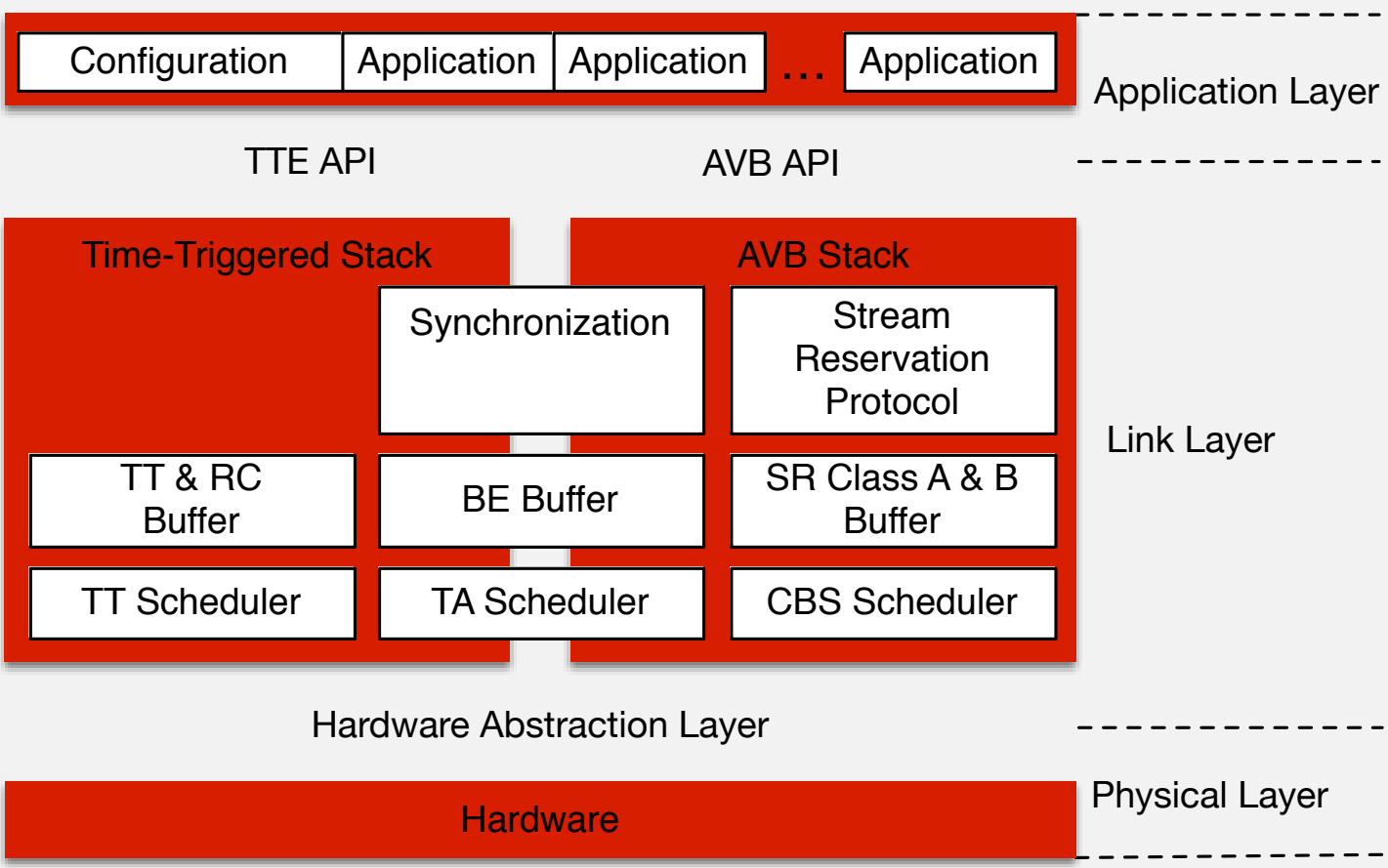
Basic elements:

- Synchronisation
- Static scheduling

Characteristics:

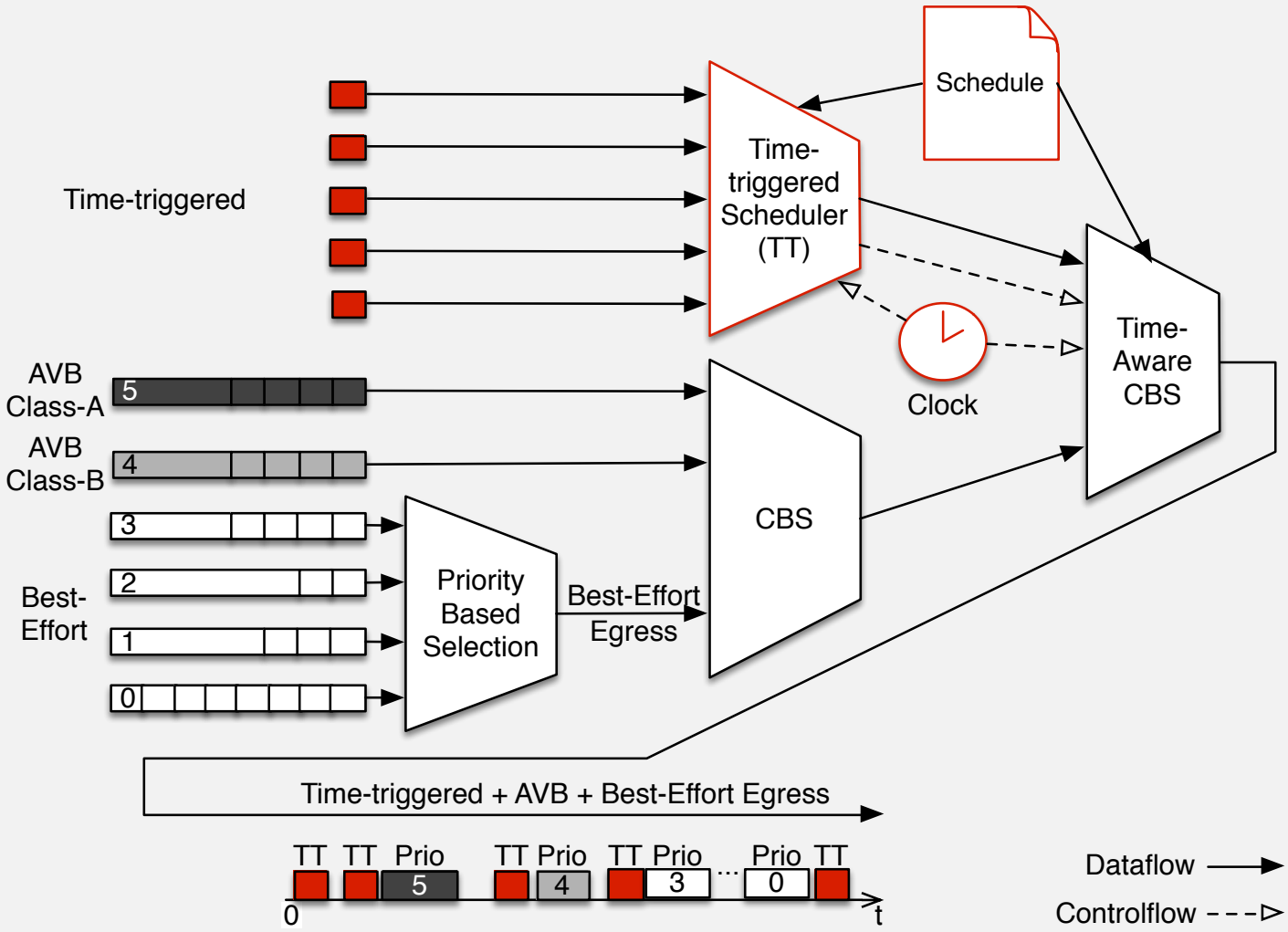
- Statically configured forwarding routes
- Statically configured send and receive times
- End-to-end latency of less than 100µs possible
- Jitter in the order of nanoseconds

System Architecture
Software Partitioning



Scheduling & Queueing

Realization of AVB with TT traffic



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Platform

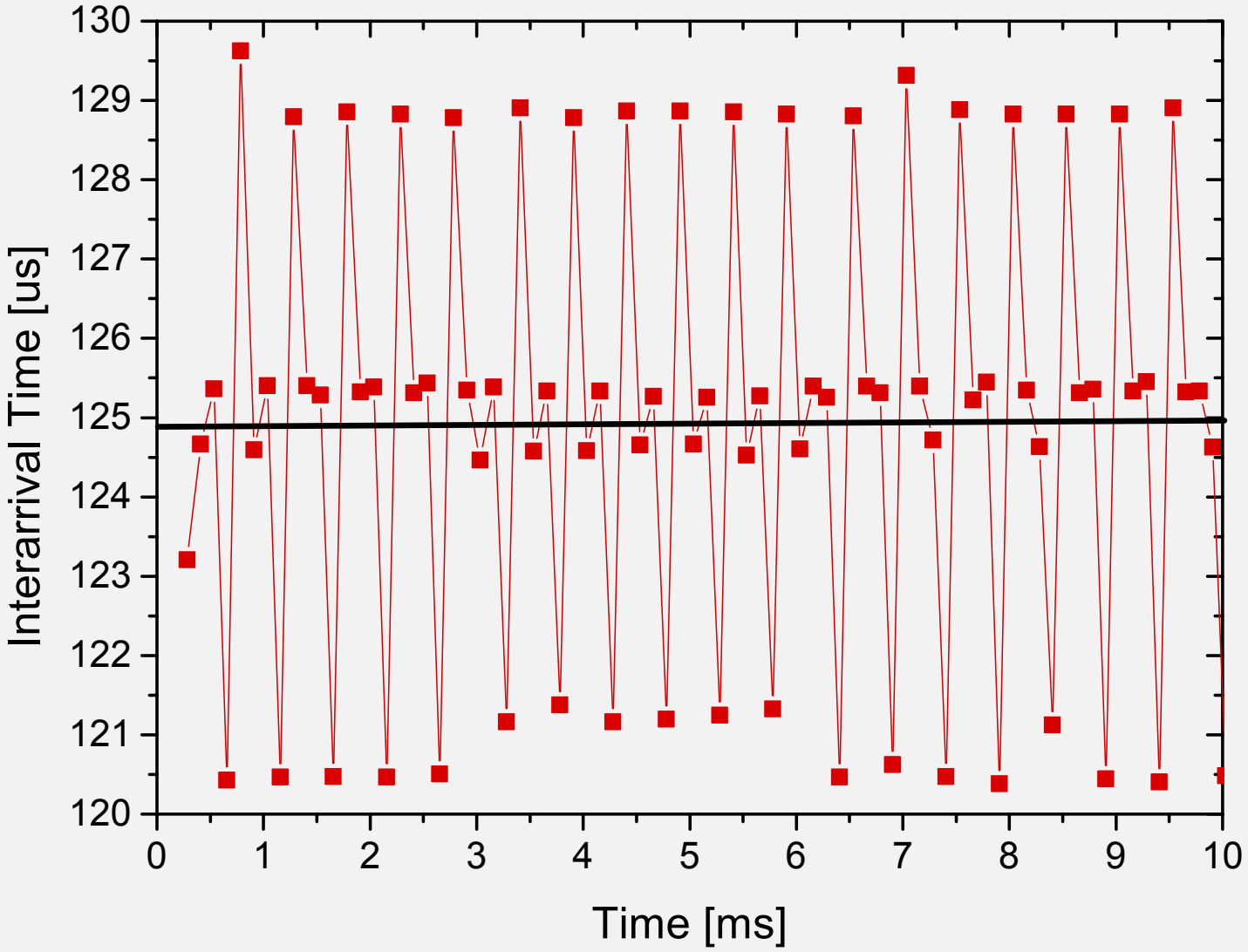
- System-on-chip design[2]
- 4 concurrently usable channels (ALU)
- 200 MHz ARM9 CPU
  - 8 kB data- and 16 kB instruction cache
  - 8 kB tightly coupled data memory
- Data switch architecture instead of system bus architecture
- Timestamping with nanosecond resolution
- Rate correctable system time with 2^{-28} ns resolution

[2] Kai Müller et al.:"A Real-time Ethernet Prototype Platform for Automotive Applications". Sept. 2011.

Significant Modules

Module	Memory Consumption [kB]	%
Talker	4.7	2.5
Credit Based Shaper	55.8	29.0
AVB	62.2	32.5
AVB API	8.8	4.6
AVB Timer	2.0	1.0
MRP	41.8	21.8
MMRP	4.9	2.5
MVRP	4.8	2.5
SRP	7.1	3.7
Total	192.1	100.0

Performance



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Conclusion

- Real-time Ethernet likely to enter in-car domain
- Mixed-critical applications require specialised system software
- First approach to IEEE 802.1Qbv capable software stack
- Joins IEEE 802.1 AVBs credit-based shaper with scheduler for time-triggered traffic
- Low footprint microcontroller based communication architecture
- Prototype shows feasibility on system-on-chip with ARM9

Outlook

- Improve performance
- Analyze possible hardware support for shaper
- Evaluate the feasibility in automobile prototype

Software Stacks for Mixed-critical Applications

Thank you for your attention!

- Website of CoRE research group:
  http://www.haw-hamburg.de/core

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References I

[1] Jahanzaib Imtiaz, Jürgen Jasperneite, and Karl Weber. "Approaches to reduce the latency for high priority traffic in IEEE 802.1 AVB networks". In: *9th IEEE International Workshop on Factory Communication Systems (WFCS 2012)*. 2012, pp. 161–164. ISBN: 978-1-4673-0693-5.

[2] Institute of Electrical and Electronics Engineers. *IEEE 802.1BA - IEEE Standard for Local and metropolitan area networks - Audio Video Bridging (AVB) Systems*. Standard IEEE 802.1BA-2011. IEEE, Sept. 2011.

[3] Kai Müller et al. "A Real-time Ethernet Prototype Platform for Automotive Applications". In: *2011 IEEE International Conference on Consumer Electronics - Berlin (ICCE-Berlin)*. Berlin: IEEE Press, Sept. 2011, pp. 221–225. ISBN: 978-1-4577-0233-4.

Extending AVB with TT traffic

Time aware credit based shaper